Executive Functioning in Adolescents Born Preterm and at Term

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Statement of Sources

I declare that this report is my own original work and that contributions of others have been duly acknowledged.

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Abstract

Executive functioning (EF) refers to a set of higher-order cognitive skills including inhibition, switching, and working memory. Previous studies have indicated that young children born preterm perform more poorly on EF tasks than those born at term, but little is known about whether these EF deficits persist into adolescence. This study aimed to identity if EF deficits were present in adolescents born preterm compared to those born at term, and to identify some potential risk factors for poorer EF performance in preterm adolescents. A total of 37 participants aged 10-17 years participated in the study, with 18 born preterm (<37 weeks' completed gestation) and 19 born at term (>38 weeks' gestation). Participants completed subtests of the Weschler Intelligence Scales, the Trail Making Test, and the Wisconsin Card Sorting Test. No significant differences were found between adolescents born preterm or at term on any intelligence or EF measures. Neither EF nor intelligence test performance could be predicted by gestational age, sex, or social risk in the preterm group. These preliminary findings indicate that adolescents born preterm and at term perform at similar levels on EF and intelligence tasks, and suggest that no interventions are needed to target EF by this age.

In recent decades, improvements in neonatal medicine have led to an increase in survival rates of children born preterm (<37 weeks' completed gestation; World Health Organisation, 2018), particularly those born very preterm (28-31 weeks' gestation; McCormick, 1993). Being born prematurely renders the developing nervous system susceptible to complications that can result in atypical development and long-term neurodevelopmental problems, including deficits in cognitive functioning, behavioural problems, and learning difficulties (Stalnacke, Lundequist, Bohm, Forssberg, & Smedler, 2015). Milder cognitive functioning deficits often do not become apparent until later in life (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009). This is problematic as routine health check-ups for children born preterm often only take place in the first few years of life to assess whether major developmental milestones are met, resulting in the potential for missing more subtle impairments in cognitive functioning such as executive functioning (EF) (Salt & Redshaw, 2006).

EF is an umbrella term for a set of interrelated, higher-order cognitive processes including inhibition, organisation, working memory, goal selection, task switching, and planning (Stalnacke, Lundequist, Bohm, Forssberg, & Smedler, 2019). Many studies have revealed that young children born prematurely perform more poorly on EF tasks compared to those born at term (Brydges et al., 2018). However, it is unclear whether EF deficits seen in young preterm children persist into adolescence. Although typically adolescents are thought of as teenagers, the World Health Organisation defines an adolescent as between the ages of 10 to 19 years old (as cited in Sawyer, Azzopardi, Wickremarathne, & Patton, 2018), and this is the definition that will be used for the current study. There is a need to further investigate the long-term impacts of preterm birth on EF and this is particularly important for the development of clinical interventions and to identify those most at risk of long-term impairments (Aarnoudse-Moens, Weisglas-Kuperus, et al., 2009). The aims of the present study were therefore to provide preliminary results on whether EF deficits are apparent in adolescents born prematurely and to identify potential risk factors that may predict poorer EF outcomes in adolescents born preterm.

Researchers' understanding of the nature of EF is still evolving and a clear definition of EF is yet to be developed. However, the three-factor model developed by Miyake, Friedman, Emerson, Witzki, and Howerter (2000) is widely accepted. Miyake et al. (2000) propose that EF consists of three interrelated but distinct factors: inhibitory control, working memory, and shifting. Inhibitory control refers to the ability to block out interfering responses or stimuli while focussing attention on the current task. Working memory involves maintaining and manipulating information in consciousness without external cues. Shifting, also known as cognitive flexibility, refers to the ability to switch between different responses, rules, or mental states. The three-factor model has been developed to explain the traditional view of EF being purely cognitive, logical, and conscious processes. These processes are known as 'cool' EF. In contrast, researchers are beginning to understand that EF also encompasses emotional, motivational, and future-oriented processes, known as 'hot' EF (Poon, 2018). Both hot and cool EF processes are required for goal-directed behaviour and adaptation to new environments, making them vital for success in a school or work environment (Costa et al., 2017). Cool EF is the most widely studied aspect in the literature so far, and it is the better predictor of academic success (Poon, 2018).

EF develops over time, with simpler processes emerging early in development and more complex, sophisticated processes emerging throughout adolescence and into early adulthood (Stalnacke et al., 2015). EF development is associated with structural and functional changes in the brain. Most of these changes occur in the prefrontal cortex (PFC), which is presumed to be the location of EF (K. Lee, Bull, & Ho, 2013). There is a period of high plasticity of the PFC in the preschool years, during which EF develops rapidly. Another sensitive period of plasticity is thought to occur during adolescence, during which there is substantial reorganisation of the PFC and PFC grey matter reaches its peak. After this, regressive changes take place in the PFC, including cell death, synaptic pruning and loss of grey matter, which are proposed to reflect the refinement and specialisation of EF (Zelazo & Carlson, 2012). The nature of EF also changes from childhood to adolescence. The three-factor model proposed by Miyake et al. (2000) describes EF in pre-adolescence and beyond, with a single-factor model apparent during childhood. This reflects the increasing specialisation of EF processes over time (K. Lee et al., 2013). EF varies across individuals; however, studies have shown that EF is often impaired in children born prematurely.

Many cross-sectional studies have focussed on EF when comparing young children born preterm to age-matched controls born at term (38-41 weeks' gestation). These studies have contributed to a growing body of literature demonstrating that young children born preterm perform more poorly than controls on a range of EF measures and across all domains of EF (e.g., Aarnoudse-Moens, Smidts, Oosterlaan, Duivenvoorden, & Weisglas-Kuperus, 2009; P. J. Anderson & Doyle, 2004; Bohm, Smedler, & Forssberg, 2004; Edgin et al., 2008; O'Meagher, Kemp, Norris, Anderson, & Skilbeck, 2017). A recent meta-analysis of EF task performance revealed that children born very preterm performed 0.51 standard deviations (SDs) below controls born at term (Brydges et al., 2018). Another recent meta-analysis separated EF into the three components of Miyake et al.'s (2000) model. That meta-analysis revealed that preterm children performed 0.52 standardised mean difference (SMD) below term controls on working memory, 0.39 SMD below on inhibition, and 0.51 below on cognitive flexibility (Van Houdt, Oosterlaan, Wassenaer-Leemhuis, Van Kaam, & Aarnoudse-Moens, 2019). These findings occur even when controlling for the effects of IQ and processing speed, indicating that EF specifically underlies the cognitive deficits seen in children born preterm (Aarnoudse-Moens, Smidts et al., 2009). Furthermore, Delane et al. (2016) used a dual-task method and found that the poorer EF performance seen in children born preterm is due specifically to EF and not due to a general cognitive deficit. These studies have typically focussed on children between the ages of 4 and 8 years old, when children usually enter school or are in primary school.

While many studies have investigated EF in young children who were born preterm, research investigating EF in older children and adolescents born preterm is lacking. It is unclear whether the EF deficits seen in young preterm children are the result of a maturational lag, if they worsen over time, or if they represent stable, long-term impairments. This is known as the 'delay-deficit' dilemma (Baron, Weiss, Litman, Ahronovich, & Baker, 2014). Findings have been inconsistent in the research conducted so far on EF in older individuals. Some studies have found that adolescents and young adults born preterm show no significant differences in EF compared to age-matched controls (e.g., Everts, Schone, Murner-Lavanchy, & Steinlin, 2019; Heinonen et al., 2018). One longitudinal study revealed that EF improved more strongly from childhood to adolescence in those born preterm compared to term controls (Everts et al., 2019). By adolescence the preterm group had reached the same performance levels as the term group and, unexpectedly, were performing at a higher level on cognitive flexibility and inhibition tasks. These findings suggest that EF may develop atypically in individuals born preterm, in that they catch up with their term peers as they mature (Sansavini, Guarini, & Caselli, 2011).

However, other cross-sectional and longitudinal studies have reported no evidence of a ‘catch-up’ in individuals born preterm from early childhood to adolescence and adulthood, instead finding that EF deficits persist, with preterm groups consistently performing more poorly than controls when assessed at different time-points (Allin et al., 2008; Madzwamuse, Baumann, Jaekel, Bartmann, & Wolke, 2015; Narberhaus et al., 2008; Stalnacke et al., 2019). Furthermore, MRI scans show long-lasting reduced cerebral volume, decreased cortical surface area, altered neural pathways and reduced white matter in individuals born preterm (Limperopoulous et al., 2005; Myers et al., 2010; Narberhaus et al., 2008). These findings suggest that the effects of preterm birth are long-lasting, and that EF represents a stable, persistent deficit in individuals born preterm. It is important to address the ‘delay-deficit’ dilemma, particularly for clinical reasons. Resolving the controversies regarding whether problems with EF represent a maturational lag or a persistent deficit in older children and adolescents born preterm may help to establish what age screening for impairments should take place, when to target interventions, and how seriously to consider early childhood results with regard to long-term outcomes (Baron et al., 2014).

Risk Factors

Environmental and biological factors may play a role in the inconsistent findings in the literature regarding whether EF deficits persist into adolescence. In most studies that have investigated EF in adolescents born preterm, researchers have viewed individuals born prematurely as a homogenous group, ignoring individual differences. However, it is important to consider individuals born preterm as a heterogenous group, with individual differences in gestational age, medical, and social risk factors likely influencing EF outcome in preterm adolescents (Ford et al., 2011). Like previous studies investigating overall EF differences between those born preterm and at term, most studies investigating potential risk factors for poorer EF performance have also been conducted with children, with very few conducted with adolescents. It is important to also investigate potential risk factors in preterm adolescents, as the effects of risk factors may change over time. For example, medical risk factors and gestational age may be more important in childhood, and social risk factors may be more important in adolescence (Aarnoudse-Moens, Weisglas-Kuperus, Duivenvoorden, Oosterlaan, & van Goudoever, 2013). Furthermore, very few studies have investigated the role of both social and medical risk factors simultaneously, making it difficult to compare the relative importance of both (Taylor & Clark, 2016). Identifying risk factors provides an important opportunity to detect preterm individuals most at risk of EF impairments and to develop interventions in the future for preterm populations. As there is a presumed period of EF reorganisation in adolescence, this may be a particularly useful time to target interventions (Zelazo & Carlson, 2012).

Substantial neurodevelopment occurs in the late stages of gestation and being born prematurely disrupts this normal development. It is widely assumed that the effects of preterm birth are dependent on a gestational age gradient, with individuals born at an earlier gestational age experiencing more disruption of neurodevelopment and therefore a greater degree of functional impairment than those born at or closer to term. However, there is surprisingly little research investigating the gestational age gradient and its relation to EF performance. Researchers have generally focussed on EF in individuals born extremely preterm (< 28 weeks) and very preterm (28-31 weeks), with very few studies including individuals born moderately preterm (32-34 weeks) or late preterm (34-37 weeks) (Johnson et al., 2015). As most preterm births are moderately and late preterm, it is particularly important to investigate the effects of later gestational ages on EF (Blencowe et al., 2013).

Even the few studies that have investigated the effect of gestational age on EF performance have typically included a limited range of gestational ages. Ritter, Nelle, Steinlin, and Everts (2013) assessed EF performance in eight- to twelve-year-old children born very preterm compared to term controls. They found that later gestational age significantly predicted better inhibition, but that gestational age did not significantly predict working memory or cognitive flexibility. Lundequist, Bohm, Lagercrantz, Forssberg, and Smedler (2014) investigated a range of gestational ages in 18-year-olds and found that those born extremely preterm had the poorest EF performance compared to term controls. Unexpectedly, they found that that those born very preterm performed at the same level as the term controls, while those born moderately preterm performed significantly more poorly. Studies that have reported poorer EF performance in adolescents born preterm have generally included only extremely and very preterm individuals, whereas studies that have reported no difference in EF performance have usually not specified the average gestational age of participants. The limited research on adolescents born at later gestational ages makes it difficult to determine the effect of the gestational age gradient on EF performance in adolescence (Van Houdt et al., 2019).

Medical risk factors are also thought to play a role in EF outcome for preterm individuals. However, due to the variability in medical complications associated with preterm birth, it is difficult and often impractical to investigate the role of medical risk factors in EF performance. O'Meagher et al. (2017) used length of hospital stay following birth as an indicator of medical complications and found that it did not significantly predict EF performance in children born preterm. Aarnoudse-Moens et al. (2013) also reported that neonatal medical complications did not significantly predict EF performance in children born very preterm. In contrast, another study found that severe neonatal brain injury was the most significant predictor of poorer EF performance in adolescents born preterm (Luu, Ment, Allan, Schneider, & Vohr, 2011). It is possible that these inconsistent findings can be explained by the different types and severity of medical complications investigated in each study. Severe neonatal brain injury may disrupt the development of basic processes that lay the foundation for later brain development, thus disadvantaging later EF development and having long-lasting effects on EF in those born preterm. In contrast, other common medical complications associated with preterm birth, such as respiratory issues, may not have such an effect on neurodevelopment.

Socioeconomic factors, including socioeconomic status (SES) and level of parental education, may also play a role in EF performance. The financial stress associated with low SES may reduce parents' ability to provide an adequately nurturing, responsive and stimulating environment for the development of EF (Clark & Woodward, 2015; Leviton et al., 2018). Indeed, high social risk characterised by a low SES has been shown to strongly predict poorer EF performance in young preterm children (O'Meagher et al., 2017). Higher education levels of the primary caregiver have been shown to strongly predict better EF performance in those born prematurely, in both childhood (Aarnoudse-Moens et al., 2013; O'Meagher et al., 2017) and adolescence (Leviton et al., 2018; Luu et al., 2011). In contrast, another study found no significant effect of parental education on EF in children 8-12 years old (Ritter et al., 2013). However, this study was conducted in Switzerland, where SES and education levels are relatively high and may therefore not accurately represent the impact of low SES. Nevertheless, it is possible that the impact of SES on EF decreases with age, and it is therefore important to further investigate its role in older children and adolescents born preterm (Aarnoudse-Moens et al., 2013).

Another potential risk factor for EF impairments in adolescents born preterm is being born male. Males appear to be neurodevelopmentally disadvantaged in general, being more likely to be born prematurely and having higher rates of mortality and morbidity at birth (e.g., Kent, Wright, & Abdel-Latif, 2012). However, there is limited research on the impact of male sex on EF. Although being male has been shown to significantly predict global cognitive impairment at approximately two years of age, the effect was no longer significant after age five (Linsell, Malouf, Morris, Kurinczuk, & Marlow, 2015). Furthermore, Van Houdt et al. (2019) found no effect of sex on EF performance in children four to fourteen years old. In contrast, Bohm, Smedler, and Forssberg (2004) found that females outperformed males on EF tasks in early childhood, although this was true for both the preterm and term groups. One study conducted in adolescents revealed that in the extremely and very preterm groups, females outperformed males, whereas in the moderately preterm groups, males outperformed females, indicating that female sex may be a protective factor against EF impairment at earlier gestational ages (Lundequist et al., 2014). However, there is also some evidence for a cross-over effect occurring at approximately 12-13 years old in those born at term, when males switch from performing at a higher level than females to performing more poorly (V. A. Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001). Overall, the mixed findings on sex differences in EF performance warrant further investigation in adolescents born preterm.

Assessing EF

Inconsistent findings in the literature on EF in preterm adolescents are further complicated by a lack of commonly used neuropsychological measures of adolescent EF. Further, studies assessing EF in preterm groups have used a wide range of EF measures, making it difficult to compare findings across studies (Aarnoudse-Moens, Smidts, et al., 2009). EF can be assessed using both performance-based assessment and self and informant ratings of everyday EF behaviours, both of which have strengths and limitations. Behavioural ratings are thought to measure ‘hot’ aspects of EF, and may reflect everyday functioning more accurately. However, they are also subject to biases in several factors, including informant characteristics and the environment in which the individual is observed (Isquith, Crawford, Espy, & Gioia, 2005).

Performance-based measures of EF measure ‘cool’ EF components. They are more objective and more accurately assess the underlying cognitive processes, but there is surprisingly limited information on how well they predict everyday EF functioning in this age group (O’Meagher, Norris, Kemp, & Anderson, 2019; Toplak, West, & Stanovich, 2013). Many commonly used performance-based EF assessments have been developed for use in younger children, making them too simple for use in older children and adolescents, or have been developed for use in adults and may not accurately reflect the real-life EF tasks encountered by older children and adolescents (Chan, Shum, Toulopoulou, & Chen, 2008). Despite the limitations of assessing EF using performance-based tasks, these tasks are widely used in clinical assessments, are useful for measuring more specific aspects of EF processes, and more accurately predict academic success (Poon, 2018; Toplak et al., 2013). For these reasons, they will be the focus of the current study.

Researchers investigating EF in preterm groups using performance-based assessments often use both direct tests of EF and subtests of intelligence tests, as there is considerable controversy in the literature regarding the relationship between EF and intelligence. Some studies report a large overlap between EF and intelligence tests, whereas others report trivial correlations (e.g., Ardila, Pineda, & Roselli, 2000; Buczylowska & Peterman, 2017; Davis, Pierson, & Finch, 2011). Furthermore, in a clinical context, intelligence tests are often used to assess EF in a general sense, as they are relatively quick and easy to administer (P. J. Anderson & Doyle, 2008). However, as intelligence tests are not designed to measure EF, they are likely not sensitive enough to accurately evaluate executive dysfunction without considering more pure EF assessment as well (Davis et al., 2011).

Present Study

The aims of the current study were to present preliminary results regarding whether EF deficits are present in adolescents born preterm (<37 weeks' completed gestation) compared to those born at term (>38 weeks' gestation), and to identify potential risk factors for poorer EF performance in preterm adolescents. As noted above, there are mixed findings in previous literature on adolescents. Nevertheless, those born preterm are at thought to be at a higher risk of EF and intelligence deficits (P. J. Anderson & Doyle, 2004). It was therefore hypothesised that the preterm group would perform significantly more poorly on performance-based measures of EF and intelligence than those born at term. Although research is lacking on the influence of risk factors on EF deficits in adolescents, based on previous research on risk factors in young preterm children, it was hypothesised that poorer EF and intelligence performance in adolescents born preterm could be predicted by being born at an earlier gestational age, having a longer hospital stay following birth, being male, and having a higher social risk.

Method

Participants

The current study represented the first recruitment wave of a planned larger study. We aimed to recruit an initial 40 participants (20 term, 20 preterm) of the overall planned 174 participants (88 term, 88 preterm). The overall planned sample size reflects the minimum number of participants required to reach a power of 0.95 and detect a moderate effect size of 0.5 ((Faul, Erdfelder, Lang, & Buchner, 2009). A total of 37 adolescents between 10 and 17 years old participated in the current study. Of those, 18 were born preterm and 19 were born at term. The term group consisted of 12 males and 7 females, while the preterm group consisted of 6 males and 12 females. Other demographic information including the mean chronological age, gestational age, and social risk, of each group can be found in Table 1 below. In the preterm group, 4 participants were born extremely preterm, 4 very preterm, 3 moderately preterm, and 7 late preterm. One parent of each adolescent participant in the study was also recruited (*n* = 37), to provide demographic information.

Table 1

Demographic Information for the Preterm and Term Groups

	Preterm				Term			
	M	*SD*	*Min.*	*Max.*	*M*	*SD*	*Min.*	*Max.*
Chronological age (years)	12.1	2.15	10	17	12.9	2.35	10	17
Gestational age (weeks)	31.8	3.92	24	37	40.1	1.37	38	42
Social risk score	1.94	1.86	0	7	1.11	1.24	0	4

Participants were recruited through advertisements placed in government and non-government school newsletters in the Greater Hobart and Launceston areas, Facebook parenting and premature birth support groups, and media coverage on television, radio, and newspaper. Exclusion criteria included a previous head injury and non-fluency in English.

Measures

The *Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993):* The WCST is a measure of general EF, inhibition, and cognitive flexibility (Greve, Stickle, Love, Bianchini, & Standord, 2005). The test begins with four stimulus cards laid out in front of the participant. The stimulus cards vary according to shape, colour, and number. The participant is instructed to match cards from two decks to the stimulus cards according to certain rules. However, they are not told anything about the sorting principles. The experimenter provides verbal feedback to indicate whether the participant’s match is right or wrong, and the participant must use this information to find out what the rule is. The rule changes without warning after ten consecutive correct matches. The test ends when a participant has completed six categories or when all 128 cards have been sorted.

A number of different scores can be calculated from the WCST. However, as there is redundancy in reporting every score (Bowden et al., 1998) we chose to report the number of perseverative responses. This is widely regarded as the most useful score to report, as it is considered the score that most accurately captures EF (Heaton et al., 1993; Nyhus & Barcelo, 2009). The number of perseverative responses gives a measure of the participant's tendency to perseverate, meaning to maintain sorting according to one principle despite feedback that it is incorrect (Heaton et al., 1993).

The Trail Making Test (TMT; Army Individual Test Battery, 1944): The TMT is a timed test consisting of two parts, with practice trials for each part. Part A requires participants to draw a line connecting a series of numbers in order, from 1 to 25. Part B requires participants to draw a line connecting a series of 25 numbers and letters, alternating between numbers and letters (e.g., 1-A-2-B…). There is a maximum time limit of 300 seconds. Errors made by participants contribute to the total time taken as the participant is stopped by the examiner and instructed to correct them. The time taken to complete Part A provides a measure of visual search and motor speed skills, whereas the time taken to complete Part B provides a measure of cognitive flexibility (Kortte, Horner, & Windham, 2002). The time calculated from Part B minus Part A is thought to provide a purer measure of EF, specifically cognitive flexibility and working memory (Sanchez-Cubillo et al., 2009), and so this measure was used in the current study.

The Weschler Intelligence Scale for Children (WISC-V; Weschler, 2014): Participants aged 10-16 completed five subtests of the WISC-V. The subtests were administered by either a registered clinical psychologist or a provisional psychologist under the supervision of a registered clinical psychologist. The WISC-V is an intelligence test used to determine scores on general and specific aspects of cognitive functioning. The five subtests used in this study were Block Design, Information, Coding, Digit Span, and Matrix Reasoning. The Block Design subtest involves using a set of blocks to recreate a pattern. It forms part of the Visual Spatial Index and measures nonverbal concept formation and the ability to analyse, synthesise and manipulate visual information. The Information subtest requires participants to verbally answer general knowledge questions. It forms part of the Verbal Comprehension Index and measures storage and retrieval from long-term memory. For the Coding subtest, participants copy as many symbols as possible in two minutes into boxes below their corresponding numbers. Coding forms part of the Processing Speed Index and measures visual scanning, attention, and cognitive flexibility. The Digit Span subtest involves repeating sets of numbers in order and backwards. This subtest forms part of the Working Memory Index and measures auditory recall and mental manipulation. Finally, the Matrix Reasoning subtest requires participants to select the correct picture that completes the pattern. Matrix Reasoning forms part of the Fluid Reasoning Index and measures problem solving and pattern analysis.

The Weschler Adult Intelligence Scale (WAIS-IV; Weschler, 2008): The 3 participants aged 17 years old completed the same five subtests of the WAIS-IV as described above.

Social Risk Index (Roberts et al., 2008): A social risk index developed for use in preterm populations was used to determine the level of social risk of each adolescent participant. This index is comprised of six risk factors rated from 0 (low risk) to 2 (high risk) (see Appendix A for scoring procedure): family structure, maternal age at birth of adolescent participating in the study, education level of the primary caregiver, occupation of the primary income earner, employment status of the primary income earner, and language spoken at home. The scores on each risk factor are then tallied to give an overall score between 0 and 12. Only the preterm group were included in the analyses predicting performance from social risk, but mean social risk scores for each group can be found above in Table 1.

Procedure

The study was approved by the Tasmanian Social Sciences Human Research and Ethics Committee (H0018018; Appendix B). Approval was also obtained from the Department of Education to contact government schools regarding advertising the study in school newsletters (file number 2019-28; Appendix C). Upon arrival at the University of Tasmania, parents were provided with an information sheet (Appendix D) and signed a consent form (Appendix E). The adolescent participants were then taken to a separate room and provided with their own information sheet (Appendix F). Adolescents provided verbal assent and could also choose to sign a consent form (Appendix G), depending on their age and preferences.

The adolescent participants completed the three performance-based measures of EF and intellectual functioning with the researchers: the WISC-V/WAIS-IV, the WCST, and the TMT. The WCST and the TMT were administered by the Honours student researcher. As the WISC-V and WAIS-IV are restricted tests, they were administered by a registered clinical psychologist, with the Honours student researcher present. Order of test administration was varied so that some participants completed the WCST and TMT prior to the WISC-V, whereas others completed the WISC-V first. During this time, the parents completed the social risk index in a separate room. They were also asked to report their child’s gestational age and the length of hospital stay following birth.

This study was conducted with another Honours student researcher, who administered a set of behavioural questionnaires not reported here, as part of her separate thesis. Overall, it took between 60-90 minutes to complete the testing session. Families received a summary report of their child's performance.

Design & Analyses

This study employed a cross-sectional, between-groups design comparing preterm and term groups on performance-based measures of EF and intelligence. This study also used a correlational design to examine the relationship between gestational age, sex, social risk factors, medical risk factors, and EF performance.

Independent-samples *t*-tests with Bonferroni corrections for multiple comparisons were conducted to compare the performance of the preterm and term groups on intelligence subtests. As standardised scores are not available for the TMT or WCST, analyses of covariance (ANCOVA) were conducted to compare the term and preterm groups' performance on these tasks while controlling for the effects of age. We did not control for sex, as there are no systematic sex differences in intelligence test scores, and there are no strong theoretical reasons for controlling for sex on EF tasks in an adolescent population.

Separate forced-entry multiple linear regression analyses were conducted to determine if EF and intelligence task performance could be predicted from gestational age, sex, social risk, and length of hospital stay following birth. Due to the small sample size, bootstrapping was performed to determine bias-corrected and accelerated 95% Confidence Intervals (CIs) for each regression coefficient. All analyses were conducted using Jamovi Version 1.0.4.0, with the exception of bootstrapping, which was conducting using IBM SPSS Version 24.

Results

Between-groups Comparisons

Assumptions were checked prior to running all analyses. Inspection of histograms and Q-Q plots revealed some issues with skewness and kurtosis. However, as *t*-tests and ANCOVA are fairly robust to violations of normality (Field, 2018), and non-parametric tests revealed the same pattern of significance, standard parametric analyses were conducted and are reported here. Inspection of box plots indicated the presence of outliers in all dependent variables. This was not surprising given the small sample size. Following inspection of each unusual case, all outliers were retained because it was determined that they likely reflected true cases rather than systematic error in measurement. Levene’s test was non-significant for all analyses, indicating that the assumption of homogeneity of variances was met.

To compare the preterm and term groups on measures of intelligence, independent samples *t*-tests were conducted with Bonferroni adjusted *p*-values (0.01) to control for multiple comparisons (Table 2). There were no significant differences between the preterm and term groups on any of the intelligence subtests. Effect sizes were small for the Coding, Block Design, and Information subtests, and medium for the Matrix Reasoning and Digit Span subtests. To maximise power, all variables were entered into a Multivariate Analysis of Variance. The pattern of significance did not change, Pillai’s V = 0.501, F (20, 124) = 0.887, p = 0.604, hence *t*-tests have been reported for ease of interpretation.

Table 2

Independent Samples t*-test Results for Intelligence Subtests*

	Preterm		Term					95%CI		
	M	*SD*	*M*	*SD*	*t*	*df*	*p*	Lower	Upper	Cohen's *d*
Coding	8.83	2.55	9.42	2.97	0.64	35	0.524	-2.44	1.26	0.21
Block Design	9.06	3.17	10.20	3.39	1.02	35	0.314	-3.30	1.09	0.34
Information	9.61	3.15	10.60	2.99	0.96	35	0.344	-3.01	1.08	0.32
Matrix Reasoning	9.22	2.92	11.00	2.65	1.94	35	0.060	-3.64	0.08	0.64
Digit Span	8.72	2.37	10.60	3.42	1.91	35	0.065	-3.83	0.12	0.63

As significance values may have been inflated by the small sample size, Bayes factors were calculated for each intelligence subtest comparison, to aid interpretation of results (Table 3). Bayes Factors were calculated using the default prior distribution in Jamovi. Interpretation of the Bayes factors following the guidelines of Jeffreys (1961) and M. D. Lee and Wagenmakers (2014), indicated that for the Coding, Block Design, and Information subtests, there was anecdotal evidence for the null hypothesis (i.e., no difference between the preterm and term groups). For the Matrix Reasoning and Digit Span subtests, there was anecdotal evidence for the alternative hypothesis (i.e., that the preterm group performed more poorly than the term group on these tasks).

Table 3

Bayes Factors for the Intelligence Subtests

Subtest	BF_{10}
Coding	0.375
Block Design	0.478
Information	0.457
Matrix Reasoning	1.347
Digit Span	1.284

As standardised scores are not available for the TMT or WCST, analyses of covariance controlling for the effect of age were conducted to compare performance of the term and preterm groups on these tasks (Table 4). One case was missing from the WCST due to problems with test administration. Again, no significant differences were found between the term and preterm groups. Effect sizes were trivial for performance on the TMT Part B minus Part A (TMTB-A), and small for the number of perseverative responses on the WCST.

Table 4

Analyses of Covariance Results for EF and Intelligence Performance

	Preterm		Term					
	M	*SD*	*M*	*SD*	*F*	*df*	*p*	η_p^2
WCST	15.0	12.90	18.7	12.51	0.75	1, 33	0.393	0.022
TMT B-A	49.8	30.21	53.1	30.21	0.11	1, 34	0.745	0.003

Multiple Regression

To determine if EF and intelligence performance in the preterm group could be predicted by risk factors, seven separate forced-entry multiple linear regressions were conducted. Forced entry was chosen as although each predictor variable has strong theoretical reasons for being included in the model, there was no theoretical basis for specifying a hierarchy of entry. The predictor variables were length of hospital stay, gestational age, sex, and social risk. As sex is a categorical variable, it was dummy coded, with male being coded as 1 and female as 0. Inspection of histograms and Q-Q plots revealed some issues with normality, particularly with social risk being positively skewed. However, as regression is quite robust to violations of normality, we proceeded with the analysis (Field, 2018).

Following inspection of the correlation matrix, low correlations were apparent between most variables. Scatterplots also showed weak relationships between the variables, although none appeared quadratic or curvilinear. Multicollinearity was apparent between gestational age and length of hospital stay (r = -0.93). Length of hospital stay was subsequently removed from the regression models, as it appeared to be measuring degree of prematurity, rather than medical complications following birth, and gestational age had stronger theoretical reasons for being retained in the model. After removing length of hospital stay, all tolerance values were greater than .02 and all VIF values were less than 10, indicating no further problems with multicollinearity. Outliers were apparent from both box plots and Cook’s distance; but these were retained for the same reasons described above. Inspection of Q-Q plots indicated that residuals were normally distributed. All values on the Durbin-Watson test fell between 1 and 3, indicating that the assumption of independence of errors was met.

Unexpectedly, all regression models predicting EF and intelligence performance from social risk, gestational age, and sex, were non-significant. The models predicting performance on intelligence subtests from the three risk factors accounted for approximately 9.1% of the variance in Block Design, $R^2 = 0.091$, $F(3, 14) = 0.47$, $p = 0.711$, 32.4% of the variance in Coding, $R^2 = 0.324$, $F(3, 14) = 0.55$, $p = 0.658$, 22.5% of the variance in Information, $R^2 = 0.225$, $F(3, 14) = 0.30$, $p = 0.059$, 11.1% of the variance in Matrix Reasoning, $R^2 = 0.111$, $F(3, 14) = 0.59$, $p = 0.635$, and 37.1% of the variance in Digit Span, $R^2 = 0.371$, $F(3, 14) = 0.28$, $p = 0.236$. Adjusted R^2 values for each model were uninterpretable (see Appendix H), indicating the models have no predictive value. See Table 6 for the individual predictors. While the overall model predicting Digit Span performance was non-significant, social risk was found to significantly predict Digit Span performance. However, given the poor fit of the overall model, this is likely a spurious finding.

As noted earlier, because of the small sample size and skewed distributions of some variables, bootstrapping was also performed for all regression models. All bootstrapped 95% CIs for the regression co-efficients included zero, indicating they were non-significant. As the pattern of significance did not change, only the original regression models are reported for both EF and intelligence analyses.

Table 5

Individual Predictors of Intelligence Subtest Performance

	B	95%CI Lower	95%CI Upper	*SE*	*β*	*t*	*p*
Coding							
Intercept	11.42	-0.81	23.64	5.70		2.00	0.065
Sex	0.29	-2.88	3.46	1.48	0.06	0.20	0.848
Gestational age	-0.05	-0.42	0.32	0.17	-0.08	-0.32	0.756
Social risk	-0.49	-1.34	0.37	0.40	-0.36	-1.22	0.241
Block Design							
Intercept	14.86	-0.47	30.19	7.15		2.08	0.056
Sex	-0.35	-4.32	3.63	1.85	-0.05	-0.19	0.854
Gestational age	-0.15	-0.62	0.31	0.22	-0.19	-0.71	0.492
Social risk	-0.43	-1.50	0.64	0.50	-0.25	-0.87	0.400
Information							
Intercept	8.86	-5.18	22.90	6.55		1.35	0.197
Sex	-3.06	-3.95	3.34	1.70	-0.05	-0.18	0.860
Gestational age	0.07	-0.35	0.50	0.20	0.09	0.36	0.726
Social risk	-0.72	-1.70	0.26	0.46	-0.42	-1.57	0.139
Matrix Reasoning							
Intercept	10.84	-3.12	24.80	6.51		1.67	0.118
Sex	0.02	-3.60	3.64	1.69	0.003	0.01	0.992
Gestational age	-0.02	-0.44	0.40	0.20	-0.02	-0.09	0.927
Social risk	-0.53	-1.51	0.44	0.45	-0.34	-1.18	0.259
Digit Span							
Intercept	6.98	-2.55	16.52	4.45		1.57	0.138
Sex	0.84	-1.64	3.31	1.15	0.17	0.73	0.480
Gestational age	0.09	-0.20	0.38	0.13	0.15	0.69	0.503
Social risk	-0.76	-1.42	-0.09	0.31	-0.60	-2.44	0.028

The models predicting EF performance from the three risk factors accounted for approximately 5.7% of the variance in perseverative errors on the WCST, R^2 = 0.057, F (3, 14) = 0.26, p = 0.852, and 6.8% of the variance in TMT performance, R^2 = 0.068, F (3, 14) = 0.34, p = 0.796. Again, adjusted R^2 values were uninterpretable for these models (Appendix H), indicating they have no predictive value. Individual predictors can be found in Table 6.

Table 6

Individual Predictors of EF Task Performance

	B	95% CI Lower	95% CI Upper	*SE*	*β*	*t*	*p*
TMT B-A							
Intercept	-16.23	-191.65	159.20	81.79		-0.20	0.846
Sex	9.04	-36.47	54.56	21.22	0.12	0.43	0.677
Gestational age	1.98	-3.32	7.28	2.47	0.22	0.80	0.437
Social risk	1.33	-10.91	13.57	5.71	0.07	0.23	0.819
WCST							
Intercept	18.57	-50.47	87.62	31.96		0.58	0.571
Sex	-1.72	-19.46	16.02	8.21	-0.06	-0.21	0.837
Gestational age	0.01	-2.11	2.12	0.98	0.002	0.01	0.995
Social risk	-1.46	-6.15	3.24	2.17	-0.21	-0.67	0.514

Discussion

The primary aim of the current study was to investigate how adolescents born preterm performed on EF and intelligence tasks compared to those born at term. Based on previous research showing that preterm children are more at risk of EF and intelligence deficits, it was hypothesised that adolescents born preterm would perform significantly more poorly on all intelligence and EF measures compared to those born at term. This hypothesis was not supported, as no significant differences were found between adolescents born preterm or at term on any of the EF or intelligence measures.

The second aim of the current study was to identify potential risk factors for poorer EF and intelligence performance in adolescents born preterm. It was hypothesised that poorer EF and intelligence performance could be predicted by lower gestational age, being male, longer hospital stay following birth, and higher social risk. This hypothesis was also not supported, as none of the regression models predicting EF or intelligence performance from the risk factors were significant, and none had any substantial predictive value.

Between-Group Comparisons

As noted above, the hypothesis that the preterm group would perform significantly more poorly than the term group on all EF and intelligence tasks, was not supported. Despite no statistically significant differences being found, some effect sizes were moderate, which may still be practically meaningful. However, interpretation of Bayesian analyses revealed only inconclusive support for both the null and the alternative hypotheses. Due to the small sample size, it is important that the findings be interpreted with caution, as the study likely did not have enough power to detect subtle differences between the groups.

If the preliminary findings of the current study are confirmed by the results of the planned larger study, this would indicate that there are no substantial differences in EF or intelligence performance between adolescents born preterm and at term. Although longitudinal studies are also needed to draw firmer conclusions, these findings suggest that the EF and intelligence deficits seen in young children born preterm are remediated by adolescence. In terms of the delay-deficit dilemma (Baron et al., 2014), the current findings provide support for the theory that EF is an area of delay in individuals born preterm, rather than a permanent deficit. This suggests that EF develops atypically in those born preterm, in that somewhere between early childhood and adolescence, they catch up to their term peers.

These findings are consistent with a previous cross-sectional study by Heinonen et al. (2018), who compared young adults born preterm to those born at term on a range of EF tasks, including the TMT. Heinonen et al. also reported no significant differences in EF between young adults born preterm and at term. The current findings are also consistent with the findings of Everts et al. (2019), who conducted a longitudinal study. Everts et al. found that EF developed more strongly from childhood to adolescence in those born preterm. By adolescence, the preterm group was performing at the same levels of the term group, and were even outperforming them on tasks assessing inhibition and cognitive flexibility. It is important to note that these studies included only participants born late preterm (Heinonen et al., 2018) or very preterm (Everts et al., 2019). Although the current study included participants across all defined degrees of prematurity (extremely, very, moderately, late), gestational age was negatively skewed, with most participants being born moderately to late preterm. Further, the mean gestational age of the preterm group in the current study was approximately 32 weeks, which is classed as moderately preterm. The present findings, along with the findings of the studies discussed above, may not be generalisable to those born extremely preterm. However, together with the results of the current study, these findings support the theory that EF follows an altered developmental trajectory in those born preterm, and that EF differences represent delay and not deficit in preterm individuals.

In contrast, the findings of the current study are inconsistent with other previous cross-sectional research that has found that older individuals born preterm perform significantly more poorly on EF tasks compared to those born at term (Madwamuse et al., 2015; Narberhaus et al., 2008). The current findings are also inconsistent with some previous longitudinal research. Allin et al. (2008) reported that their preterm group's EF and intellectual deficits observed in early childhood were not attenuated when they were later assessed in adolescence or early adulthood. Further, Stalnacke et al. (2019) found that EF remained stable from age 5.5 years to 18 years in those born preterm, indicating that early EF deficits did not remediate, and EF did not continue developing with age as it does in healthy controls. In contrast to the findings of the current study, these previous studies provide support for the theory that EF represents a stable, lasting deficit in those born preterm.

It is likely that the discrepancies between the current research findings and these previous studies can be explained by the selection criteria. The previous studies described above, that have reported persisting EF deficits in those born preterm, have included only those born very preterm or extremely preterm. In contrast, the current study recruited preterm participants right up to 37 weeks and 6 days gestation, based on the World Health Organisation's definition of preterm being less than 37 weeks' completed gestation (2018). Most preterm participants in the current study were born moderately and late preterm. Furthermore, unlike those previous studies, and although not a specific exclusion criterion, the current study did not include any participants with severe cognitive deficits or brain damage. It is possible that for individuals born at earlier gestational ages, EF remains a long-term deficit, whereas for those born at later gestational ages, EF represents a maturational lag. This is certainly not unlikely, given that significant neurodevelopment, particularly of frontal brain regions responsible for EF, occurs during the later stages of gestation. Extreme prematurity may permanently disrupt neurodevelopment. However, it is beyond the scope of the current study to draw firm conclusions regarding this possibility, and longitudinal studies including a range of gestational ages are needed to test this hypothesis.

The discrepancies between the current study and some previous research may also be attributable to the different EF tasks used. There is great variability in the types of EF tasks administered in previous research. This is particularly evident with research involving adolescent participants, due to the lack of EF measures designed specifically for this age group. The different EF tasks used make it difficult to compare findings, as task demands vary greatly. Furthermore, although the WCST and TMT are commonly used to assess EF, they were designed to assess EF impairments in adult patients with frontal lobe damage. They may not be sensitive enough to detect subtle differences in EF, or different levels of dysfunction (P. J. Anderson, 2002). These tasks, as with other performance-based EF tasks, are also not reflective of everyday tasks requiring EF encountered by adolescents in real life. Although not directly measurable, there were noticeable differences in the ways in which participants in each group approached the EF tasks. Participants in the term group had a tendency towards overthinking the tasks and trialling very complex solutions. In contrast, participants in the preterm group generally approached the tasks as expected and seemed to find them challenging without overcomplicating their approaches.

While the results of the current study indicate no differences in EF performance between adolescents born preterm and at term, we cannot rule out the possibility of differences in everyday functioning. We only assessed performance-based measures of EF, which correlate with behavioural rating questionnaires moderately at best (V. A. Anderson, Anderson, Northam, Jacobs, & Mikiewicz, 2002). Further, although performance-based measures are better for predicting academic outcomes, behavioural rating questionnaires are more reflective of everyday functioning (Poon 2018; Toplak et al., 2013). This is because performance-based tasks are conducted in a one-to-one testing environment with minimal distractions, and often demand simple responses (P. J. Anderson, 2002). This does not reflect many real-life EF tasks, which often involve multiple steps, sub-goals, and prioritisation (Chan et al., 2008). Further, the testing environment does not reflect a standard academic environment, in which there are many distractions. Our results may therefore indicate that adolescents born preterm have the same levels of EF capacity as those born at term, but this may not reflect adaptive functioning in the more complex everyday environment.

Risk Factors

Unexpectedly, the second hypothesis was also not supported. Neither intelligence nor EF performance of the preterm group could be significantly predicted by gestational age, sex, or social risk. Furthermore, the models accounted for negligible amounts of the variance in EF and intelligence performance of those born preterm. As with the between-group comparisons described above, these findings need to be interpreted with caution due to the small sample size limiting the power. A minimum of 10-15 participants per predictor has been recommended to achieve adequate power in regression analyses (Babyak, 2004). The current study included only 18 preterm participants in the regression analyses, with 3 predictors. However, if these findings are confirmed with a larger, more diverse preterm sample, they indicate that models predicting EF and intelligence performance from those risk factors are extremely poor fits for explaining performance of adolescents born preterm.

It was unexpected that gestational age did not significantly predict performance on any of the intelligence or EF tasks. Although it is widely assumed that cognitive outcomes, including EF, vary according to degree of prematurity, there is very little research investigating the gestational age gradient. Furthermore, there is a paucity of previous research including a range of gestational ages, particularly at the later end of the preterm spectrum. There is therefore very little research with which to compare the findings of the current study. Our findings are somewhat consistent with those of Ritter et al. (2013). Ritter et al. found that in older children born preterm, gestational age predicted inhibition, but did not predict performance on working memory or cognitive flexibility tasks. The current results are consistent with those of O’Meagher et al. (2017), who found that gestational age did not predict EF or intelligence performance in young children born preterm. Our findings regarding gestational age are limited by our sample. Although our preterm participants ranged from extremely preterm to late preterm, gestational age was negatively skewed, with most being born in the moderate and late categories. However, if the present study’s results are confirmed with a larger sample size covering more of the preterm spectrum, this indicates that EF and intelligence performance do not vary according to gestational age in those born preterm.

The finding that social risk did not significantly predict performance on any of the intelligence or EF tasks is surprising in the context of previous research. Although very few previous studies have examined the relationship between social risk and EF performance in those born preterm, the few studies that have examined this relationship have indicated that social risk predicts poorer performance in both preterm children (Aarnoudse-Moens et al., 2013; O'Meagher et al., 2017) and adolescents (Leviton et al., 2018; Luu et a., 2011). Further, social risk has previously been shown to predict poorer EF performance in those born at term as well (Leviton et al., 2018). There are two major mechanisms through which social risk is thought to play a role in EF performance. Firstly, higher social risk is associated with 'environmental inequality', in which individuals with higher social risk are more likely to experience exposure to environmental toxins, violence, and poor nutrition that can negatively impact maturation (Leviton et al., 2018). Secondly, the increased financial and environmental stress associated with higher social risk are thought to reduce parents' ability to provide nurturing, stimulating environments that promote healthy EF development in children (Clark & Woodward, 2015). However, the findings of the current study are consistent with those of Ritter et al. (2013), who found that social risk did not predict EF performance in older children born preterm. It is possible that social risk plays a stronger role in early childhood, and that by adolescence it no longer has an impact. This may be because as an individual progresses through school, the effects of social risk factors are diminished, as schooling can equalise opportunities for cognitive development (Ritter et al., 2013). It is also important to note that the preterm sample included in the current study reported very low overall social risk. Our findings likely do not capture the possible impact of high social risk, which may have a stronger relationship with EF performance.

Our expectation that males born preterm would perform more poorly on EF and intelligence tasks was also not met. Although this was unexpected, it is perhaps not surprising given the lack of research investigating the role of sex and the mixed findings of the few previous studies that have investigated it. Consistent with our findings, Van Houdt et al. (2019) also found no effect of being male on EF performance in children 4 to 14 years old. In contrast, Bohm et al. (2004), found that in young children born preterm, males performed more poorly than females on EF tasks. It is possible that the effects of sex diminish with age. Ultimately our findings indicate that there is no systematic association between sex and EF or intelligence performance in adolescents born preterm.

Implications

As the current study was underpowered due to the small sample size, firm conclusions cannot be drawn regarding implications of the findings. However, if the findings are confirmed with a larger, more diverse sample, there are several important clinical implications. Our findings address the 'delay-deficit' dilemma by providing support for EF representing a maturational delay in those born preterm. Although confirmation is needed with longitudinal studies, our preliminary findings indicate that the EF deficits observed in young children born preterm are remediated by adolescence. This suggests that interventions designed to enhance EF are not necessary by this age. Any interventions should be targeted at a younger age group only. Furthermore, interventions may not be necessary at all, given that EF may catch up naturally through an altered developmental pathway in individuals born preterm. Additionally, these findings suggest that early childhood results of EF assessment in those born preterm may not need to be taken so seriously, as the long-term outcome appears to be positive. As interventions are extremely costly, if interventions are not necessary for EF in preterm populations, then resources can be redistributed to other groups in need.

If confirmed, our findings also have implications for the use of age-adjustments for cognitive assessments in those born preterm. Currently in clinical practice, scores on many cognitive assessments, including the Weschler intelligence tests, are corrected for prematurity in children under the age of 3 years. Rather than using chronological age, age is adjusted for degree of prematurity by subtracting the number of weeks premature the child was. This increases the standardised score and avoids underestimating cognitive ability. Questions have been raised regarding whether scores should be adjusted for prematurity in older children (Wilson-Ching, Pascoe, Doyle, & Anderson, 2014). As our findings indicate that there are no significant differences in EF or intelligence scores between adolescents born preterm and at term, then correcting for prematurity is not necessary in this age group. If scores were to be corrected for prematurity, this would result in over-estimation of cognitive abilities. Consequently, this could impact the likelihood of detecting real deficits in individuals born preterm.

In terms of risk factors, our findings suggest that being born at a younger gestational age, being male, and higher social risk do not predict poorer EF or intelligence performance in preterm adolescents. Although these findings need to be further investigated with a more diverse sample, if confirmed, they have positive implications. As gestational age and sex cannot be modified through intervention, it is reassuring that our findings indicate that they play no substantial role in EF or intelligence performance in adolescence. Furthermore, even though some aspects of social risk can be modified through intervention, doing so can be challenging and expensive (Roberts et al., 2008). It is therefore encouraging to find that it may not predict poorer EF and intelligence performance by adolescence.

Limitations

The small sample size and limited power of the study was a major limitation. This severely impacted our ability to draw firm conclusions regarding the results.

Furthermore, there was a lack of diversity within the preterm group that limited the ability to test our regression models and impacted the generalisability of the results. Most of the preterm participants had very low overall social risk, which meant that our regression models could not be tested for fit with higher risk individuals. Most of the preterm participants were also born at the later end of the gestational spectrum, which limited our ability to investigate the impact of earlier gestational ages on performance. There were also double the number of females born preterm than males, which limited our ability to fully investigate the potential role of sex in EF performance.

The cross-sectional design is another limitation. This also impacted our ability to draw firm conclusions, particularly regarding the delay-deficit dilemma. Cross-sectional designs are not uncommon in previous studies investigating EF in those born preterm and at term. They are much cheaper and more convenient than longitudinal designs. However, longitudinal studies are necessary to track individual variability in EF development and to gain further insight into the nature of EF development from early childhood to adolescence in those born preterm.

Another limitation is that we did not examine EF as a latent variable. Instead, we treated EF as a measured variable and thus used measured variable analyses. As measured variables contain measurement error, using measured variable analyses likely resulted in biased Standard Error and parameter estimates (Baron et al., 2014). In contrast, latent variable analyses like Structural Equation Modelling (SEM) include measurement error into the model, and therefore provide error-free parameter estimates (Field, 2018). Unfortunately, as latent variable analyses, including SEM, require very a large sample sizes, they would not have been appropriate for use in this study (Baron et al., 2014).

Finally, we did not gather data on possible prior assessments that participants may have experienced. EF tasks rely on novelty, and in order for them to be valid, participants must not have previously completed the tasks or similar tasks (Basso, Bornstein, & Lang, 1999). It is possible that the participants in the preterm group had experienced similar tasks during follow-up assessments of cognitive development. In contrast, the term group may have been less likely to have completed similar tasks previously, as cognitive assessments are not normally required unless there is reason to expect delay or deficits.

Future Research

As discussed earlier, longitudinal studies involving larger and more diverse samples are needed to more thoroughly explore the development of EF in those born preterm and the impact of potential risk factors. Future research with larger samples could also be conducted using latent variable analyses, which are more appropriate for analysing EF than measured variable analyses. The current study is unique in its inclusion of the entire preterm spectrum. Future research involving larger samples could be conducted to more fully investigate the potential impact of gestational age on EF development. Furthermore, it would be interesting to examine the possible differences between the defined preterm groups, by comparing EF in those born extremely, very, moderately, and late preterm. It would also be interesting for future researchers conducting longitudinal studies to simultaneously track functional EF development and structural changes using MRI or similar technology.

To date, the few existing longitudinal studies investigating EF development in individuals born preterm have been conducted in countries with high socioeconomic statuses and top-quality medical care. Future longitudinal and cross-sectional studies investigating the impact of social risk need to be conducted with individuals across a broader range of social risk. It is particularly important for future studies to investigate EF and intelligence in preterm individuals of higher social risk.

Future research could also be conducted using different measures of EF, including tasks with differing degrees of difficulty. It would also be interesting to examine the three main components of EF separately, to determine if inhibition, cognitive flexibility, and working memory follow the same developmental trajectories in those born preterm as those born at term. However, this may not be possible, given that current EF tasks often involve the use of more than one EF component to be completed successfully.

It would also be interesting to investigate both hot and cool aspects of EF. Like the current study, most previous research has focused on performance-based measures of cool EF, but hot EF could also be assessed using behavioural rating questionnaires. It would be particularly interesting to compare performance of preterm and term groups on both hot and cool aspects, using both types of measures. Longitudinal studies could also be performed to compare the development of both aspects of EF in those born preterm. Future studies comparing preterm and term performance on both performance-based and behavioural rating measurements may be important when considering the potential clinical implications. As described earlier, performance-based measures assess capacity of EF, whereas behavioural questionnaires assess adaptive functioning. Future research using both measures may be useful in determining if there are differences between capacity and adaptive functioning in those born prematurely, and if adaptive functioning differs from those born at term.

Conclusions

The current study aimed to compare performance on EF and intelligence tasks in adolescents born preterm and at term, and identify potential risk factors for poorer performance. Our preliminary findings indicate that adolescents born preterm perform at the same level as those born at term. If confirmed with the planned larger study, this is a positive outcome. Our findings provide initial support the theory that EF represents a developmental delay in individuals born preterm, rather than a long-lasting deficit. This suggests that interventions aimed at enhancing EF development in those born preterm are not necessary. It appears that EF follows an altered developmental pathway in preterm individuals, and catches up to that of individuals born at term somewhere between early childhood and adolescence.

Although our findings regarding risk factors need to be confirmed with a larger, more diverse sample, our preliminary findings are also encouraging. Neither EF nor intelligence performance could be predicted by gestational age, sex, or social risk in preterm adolescents. The models predicting performance from these factors were extremely poor fits for this group. These findings indicate that these factors play little to no role in EF or intelligence performance in adolescents born preterm. Given that gestational age and sex cannot be modified through intervention, and social risk is difficult to modify, these initial findings are reassuring. Overall, the current study provides initial support for positive outcomes regarding intelligence and EF in those born prematurely.

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Appendix A

Social Risk Index Scoring Procedure

Scoring Procedure for the Social Risk Index (Roberts et al., 2008)

	Score		
Risk Factor	0	1	2
Family Structure	Two caregivers	Separated parents with dual custody	Single caregiver
Maternal Age at Birth	More than 21 years	18-21 years	Less than 18 years
Education of Primary Caregiver	Tertiary educated	11-12 years of formal schooling	Less than 11 years of formal schooling
Occupation of Primary Income Earner	Skilled	Semi-skilled	Unskilled
Employment Status of Primary Income Earner	Full-time employment	Part-time employment	Unemployed
Language	English only	Some English	No English

Appendix B

Ethics Approval Letter

UNIVERSITY of TASMANIA

31 May 2019

Dr Kimberley Norris
C/- University of Tasmania

Sent via email

Dear Dr Norris

REF NO: H0018018
TITLE: Executive functioning and everyday performance in school-age children born at term and preterm

We are pleased to advise that the Tasmania Social Sciences Human Research Ethics Committee approved the above project on 28 May 2019.

Please ensure that all investigators involved with this project have cited the approved versions of the documents listed within this letter and use only these versions in conducting this research project.

This approval constitutes ethical clearance by the Tasmania Social Sciences HREC. The decision and authority to commence the associated research may be dependent on factors beyond the remit of the ethics review process. For example, your research may need ethics clearance from other organisations or review by your research governance coordinator or Head of Department. It is your responsibility to find out if the approvals of other bodies or authorities are required. It is recommended that the proposed research should not commence until you have satisfied these requirements.

In accordance with the National Statement on Ethical Conduct in Human Research, it is the responsibility of institutions and researchers to be aware of both general and specific legal requirements, wherever relevant. If researchers are uncertain they should seek legal advice to confirm that their proposed research is in compliant with the relevant laws. University of Tasmania researchers may seek legal advice from Legal Services at the University.

All committees operating under the Human Research Ethics Committee (Tasmania) Network are registered and required to comply with the *National Statement on the Ethical Conduct in Human Research* (NHMRC 2007 updated 2018).

Therefore, the Chief Investigator's responsibility is to ensure that:

(1) All investigators are aware of the terms of approval, and that the research is conducted in compliance with the HREC approved protocol or project description.

(2) Modifications to the protocol do not proceed until approval is obtained in writing from the HREC. This includes, but is not limited to, amendments that:
(i) are proposed or undertaken in order to eliminate immediate risks to participants;

UNIVERSITY of TASMANIA

(ii) may increase the risks to participants;
(iii) significantly affect the conduct of the research; or
(iv) involve changes to investigator involvement with the project.

Please note that all requests for changes to approved documents must include a version number and date when submitted for review by the HREC.

(3) Reports are provided to the HREC on the progress of the research and any safety reports or monitoring requirements as indicated in NHMRC guidance. Researchers should notify the HREC immediately of any serious or unexpected adverse effects on participants.

(4) The HREC is informed as soon as possible of any new safety information, from other published or unpublished research, that may have an impact on the continued ethical acceptability of the research or that may indicate the need for modification of the project.

(5) All research participants must be provided with the current Participant Information Sheet and Consent Form, unless otherwise approved by the Committee.

(6) This study has approval for four years contingent upon annual review. A *Progress Report* is to be provided on the anniversary date of your approval. Your first report is due 28 May 2020, and you will be sent a courtesy reminder closer to this due date. Ethical approval for this project will lapse if a Progress Report is not submitted in the time frame provided

(7) A *Final Report* and a copy of the published material, either in full or abstract, must be provided at the end of the project.

(8) The HREC is advised of any complaints received or ethical issues that arise during the course of the project.

(9) The HREC is advised promptly of the emergence of circumstances where a court, law enforcement agency or regulator seeks to compel the release of findings or results. Researchers must develop a strategy for addressing this and seek advice from the HREC.

Should you have any queries please do not hesitate to contact me on (03) 6226 6254 or via email ss.ethics@utas.edu.au.

Yours sincerely

Jude Vienna-Hallam
Executive Officer I Social Sciences

Appendix C

Department of Education Approval Letter

Department of Education
EDUCATION PERFORMANCE AND REVIEW

3/75 Campbell Street, Hobart
GPO Box 169, Hobart, TAS 7001 Australia

Tasmania

File: 2019-28

15 July 2019

Kimberley Norris and Nenagh Kemp
School of Medicine, University of Tasmania
Kimberley.Norris@utas.edu.au
Nenagh.Kemp@utas.edu.au

Dear Kimberley and Nenagh

Executive functioning and everyday performance in school-age children born at term and preterm

I have been advised by the Educational Performance Research Committee that the above research study adheres to the guidelines established and that there is no objection to the study proceeding.

Please note that you have been given permission to proceed at a general level, and not at individual school level. You will still need to seek permission from the principal of the school to be involved in the study. Please provide them with the File number or a copy of this letter when approaching them for assistance.

A list of the schools where the principal has agreed to participate in the research needs to be forwarded to EPR, prior to, or soon after the commencement of the proposed activity.

A copy of your final report should be forwarded to Education Performance and Review, Department of Education, GPO Box 169, Hobart, 7001 at your earliest convenience and within six months of the completion of the research phase.

If you have further questions or concerns please contact John Kural on (03) 6165 5506.

Yours sincerely

Jason Szczerbanik
Director, Education Performance and Review

Appendix D

Parent Information Sheet

UNIVERSITY of TASMANIA

College of Health and Medicine

Executive functioning and everyday performance in school-age children born at term and preterm

PARTICIPANT (PARENT) INFORMATION SHEET April 2019

Research team: Dr Kimberley Norris and Assoc Prof Nenagh Kemp, from the Division of Psychology, in the College of Health and Medicine, at the University of Tasmania.
Contact: kimberley.norris@utas.edu.au, 6226 7199, OR nenagh.kemp@utas.edu.au, 6226 7534

1. Invitation
You are invited to participate in a research study investigating some of the factors that can influence the development of higher thinking skills and everyday behaviour of Tasmanian school-age children born at under 37 weeks' gestation, as well as children born at over 37 weeks' gestation.

2. What is the purpose of this study?
We are studying some of the factors that predict behavioural and thinking skills during the school years, both for children who were born at full term, and children who were born prematurely. We're looking at children's thinking skills, how they behave at school and at home (according the parents, teachers, and the children themselves), and at any medical and social issues that might affect them.

3. How is the study being funded?
This study does not have external funding, but is supported by the investigators' research funds. Neither investigator has any financial interest in the research.

4. Why have I been invited to participate?
We are inviting children and young people aged 10 to 17 years to participate, whether they were born prematurely or at full term. Anyone can take part, provided they speak English fluently (so that they can do the tasks) and haven't had a head injury.

Taking part in this study is voluntary. It is completely up to you, and your child, whether or not your child participates. Whatever your decision, it will not affect your relationship with the researchers. However, joining this confidential study will give us valuable information on how to identify children who may need extra assistance at school. If you or your child wish for your child to withdraw from the study once it has started, you can do so at any time without having to give a reason.

5. What will I be asked to do?
You and your child would come to the university to take part in a 60- to 90-minute session in which your child completes some assessment tasks with a researcher, and in which you and your child complete two questionnaires. Your child will also be invited to ask one teacher at their school to complete one of the questionnaires, at another time.

6. Are there any possible benefits from participation in this study?
Most of the activities are game-like, and so the children taking part are expected to have a challenging but fun session. Although there are no direct benefits to taking part, parents and teachers completing the questionnaires may feel satisfied to know that they are providing valuable information to help understand how children's thinking and behaviour develop.

If any difficulties are identified through the assessment process, suggestions that may assist your child will be sent to you after all the information is gathered. Even if you do not have concerns about your child, it is important for us to understand which children do well, and why. This information may assist other children born prematurely in the future and thus we appreciate your participation.

7. Are there any possible risks from participating in this study?
There are no specific risks related to taking part. It is possible that your child might find the assessment process challenging at times. However, it is very rare for children to become distressed, and most enjoy the tasks. In the unlikely event that you or your child becomes distressed, the assessment can be stopped, and counselling is available by a provisional psychologist at the University of Tasmania Psychology Clinic. If you would prefer, you can also contact Kids Helpline on 1800 55 1800 or speak to your child's school counsellor or psychologist.

8. What if I change my mind during or after the study?
You and your child are free to withdraw without consequences at any time while we are still running the study. However, once we have finished data collection and have de-identified the data (2 weeks following data collection), we won't be able to identify and remove specific people's data.

9. What will happen to the data when this study is over?
Data will be stored on a password-protected University of Tasmania server. Any identifiable information that is collected about your child in this study will remain confidential. It would be disclosed only with your permission (or except as required by law). Only the researchers named above will have access to your child's details and results, and these will be held securely at the University of Tasmania for a period of 7 years or until your child turns 25 years of age (whichever is longer), in accordance with the requirements of the Australian Psychological Society Code of Ethics. Investigator Dr Kimberley Norris, as a registered and practicing psychologist, is bound by this code.

10. How will the results of the study be published?
It is intended that the results will be published in a journal and potentially as a part of a conference presentation. The results may also assist us in planning further services for children born prematurely in Tasmania. In any publication, information will be provided in such a way that your child cannot be identified. If you wish to be notified about the results, please contact us.

11. What if I have questions about the study?
If you have any questions or concerns about the study, please contact us at the email addresses or phone numbers at the top of this form.

This research has been approved by the Tasmania Social Sciences Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study, you can contact the Executive Officer of the HREC (Tasmania) Network on 6226 6254 or email ss.ethics@utas.edu.au. The Executive Officer is the person nominated to receive complaints from research participants. You will need to quote H18018.

12. How can I agree to be involved?
If you agree that your child can take part, you will be asked to sign a consent form prior to your child's assessment. Your child will also be asked if they are happy to participate, and will be given the option of providing their own written consent. Please note that if your child declines to participate in the study their decision will be respected, and no data collection will take place. This information sheet is for you to keep.

Thank you taking the time to consider this study

Appendix E

Parent Consent Form

UNIVERSITY of TASMANIA

College of Health and Medicine

Executive functioning and everyday performance in school-age children born at term and preterm

PARENT CONSENT FORM April 2019

Research team: Dr Kimberley Norris and Assoc Prof Nenagh Kemp, from the Division of Psychology, in the College of Health and Medicine, at the University of Tasmania.
Contact: kimberley.norris@utas.edu.au, 6226 7199, OR nenagh.kemp@utas.edu.au, 6226 7534

By signing below, I confirm that I have read and understood the information sheet and in particular:

- I understand that my involvement in this research will include being present for a 60- to 90-minute session while my child takes part in some assessment tasks with a researcher, and while my child and I complete two questionnaires about my child's everyday behaviours at home and school. My child will also be able to invite one teacher to complete a similar questionnaire.

- I understand that participation involves no specific risks. However, if for any reason my child or I become distressed, the assessment can be stopped at any time, and counselling is available.

- I understand that if any difficulties are identified, suggestions that may assist my child will be sent to me after the information is gathered. I will also be provided with information about referral to specialist services if my child's results indicate that this would be beneficial. It is my decision about whether to follow up potential referrals to these specialist services.

- Any questions that I have asked have been answered to my satisfaction.

- I understand that all study data will be securely stored at the University of Tasmania for at least 7 years/until my child is aged 25 years. It will then be destroyed, unless I give permission for it to be used to support other research in the future.

☐ I agree that my child’s study data can be used for this specific project
☐ I agree that my child’s de-identified study data can be shared and used for future research projects in the same general area of this research

- I understand that the results of the study will be published so that my child cannot be identified as a participant
- I understand that our family’s participation in this research is voluntary
- I understand that we are free to withdraw at any time, without explanation or penalty
- If I wish, I may request that any data I have supplied be withdrawn from the research until 2023
- I agree that my child can participate in the study

Name	
Signature	
Date	

Statement by Researcher

☐ I have explained the project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

Name	
Signature	
Date	

Appendix F

Child Information Sheet

Executive functioning and everyday performance in school-age children born at term and preterm

PARTICIPANT (CHILD) INFORMATION SHEET (OPTIONAL) April 2019

Research team: Dr Kimberley Norris and Assoc Prof Nenagh Kemp, from the Division of Psychology, in the College of Health and Medicine, at the University of Tasmania.
Contact: kimberley.norris@utas.edu.au, 6226 7199, OR nenagh.kemp@utas.edu.au, 6226 7534

You are invited to take part in a study looking at some of the things that might affect how you think and organise things at home and at school. We're interested in the responses of young people who were born early, or who were born around the usual time. We're also asking young people's parents/guardians, and one of their teachers, to see if they have the same or different ideas about how participating young people seem to behave or think.

We are inviting children and young people aged 10 to 17 years to participate. Anyone can take part, provided they can speak and understand English well (so that they can do the tasks) and haven't had a head injury.

Taking part in this study is completely up to you. Whatever your decision, it will not affect your relationship with the researchers. If you want to stop participating at any time, you can do so at any time without having to give a reason.

If you take part, you would come to the university to take part in a 60- to 90-minute session to complete some tasks with a researcher, and complete two questionnaires. You will also be invited to ask one teacher at your school to complete one of the questionnaires, at another time.

If you agree to take part, you can just tell us that you want to take part, or if you prefer, you can sign a consent form. This information sheet is for you to keep.

Thank you taking the time to consider this study

Appendix G

Child Consent Form

UNIVERSITY of TASMANIA

College of Health and Medicine

Executive functioning and everyday performance in school-age children born at term and preterm

CHILD CONSENT FORM (OPTIONAL, for children who wish to provide written consent, rather than just verbal assent) **April 2019**

Research team: Dr Kimberley Norris and Assoc Prof Nenagh Kemp, from the Division of Psychology, in the College of Health and Medicine, at the University of Tasmania.
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I'm signing my name below to say that I have understood what I need to do to take part in this project.

- I understand that I will do some tasks with the researchers at the university and fill in a form with some questions about how I act and think at home and at school. It will take one to one-and-a-half hours of my time.
- I understand that it's okay to say if I want to stop at any point.
- I understand that I can ask one teacher at my school if they will fill in a form about how I act at school.
- I have asked any questions that I have about the project.
- No one apart from the university researchers will know that I've taken part, and my name won't be used if the researchers write about their project.
- I agree to take part in this project.

Name	
Signature	
Date	

Statement by Researcher

☐ I have explained the project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

Name	
Signature	
Date	

Appendix H

Adjusted R^2 Values for Overall Models

Adjusted R^2 *values for overall models predicting intelligence and EF task performance*

Subtest	*Adjusted* R^2
Coding	-0.087
Block Design	-0.104
Information	-0.059
Matrix Reasoning	-0.079
Digit Span	0.236
WCST	-0.161
TMTB-A	-0.131